# Hurricane Imaging Radiometer (HIRAD) Wind Speed Retrieval Assessment With Dropsondes

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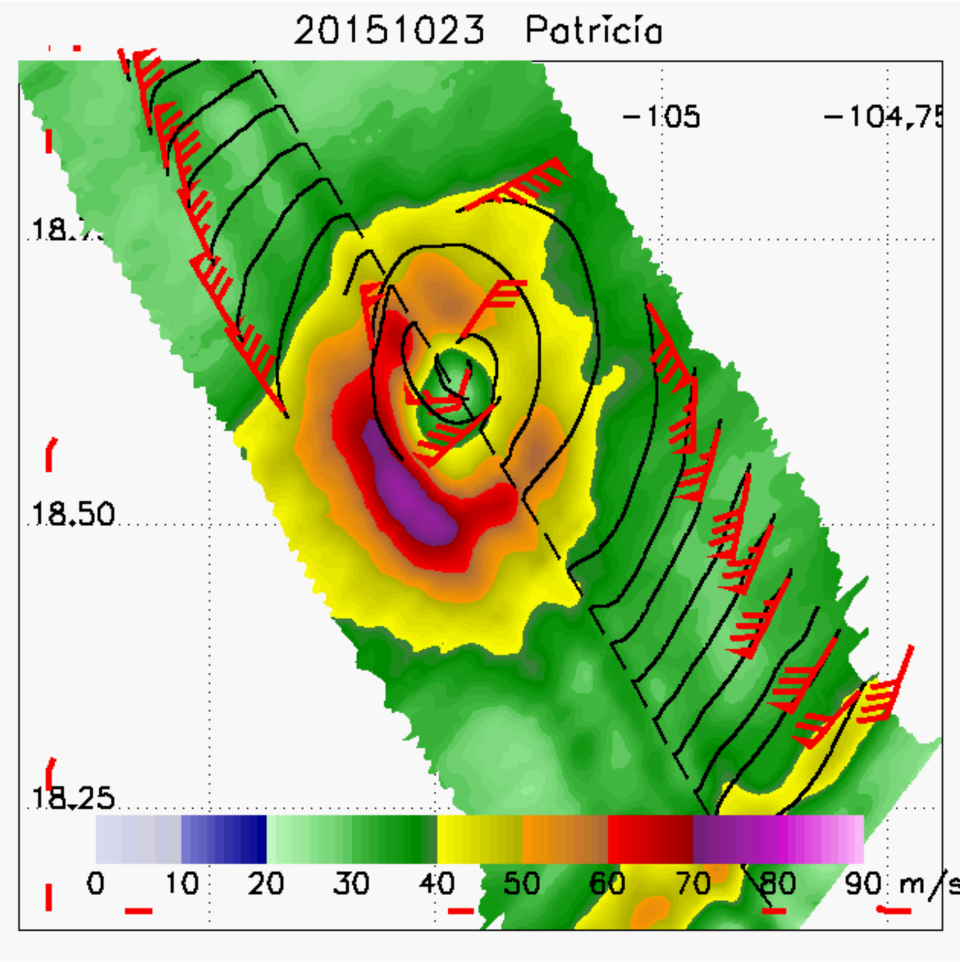
# Acknowledgments


- Funding from Office of Naval Research Tropical Cyclone Intensity (TCI) program
- HDSS dropsonde data from Yankee Environmetal Systems (YES), quality-controlled by Michael Bell and TCI colleagues
- Idealized model output provided by Dave Nolan

# HIRAD (Hurricane Imaging Radiometer)

- **Objectives:**
  - Map surface wind speed over wide swath (~50-60 km, for aircraft > FL600) in hurricanes
  - Provide research data for understanding hurricane structure, intensity change
  - Enable improved forecasts, warnings, decision support
- **Technical Approach:**
  - Retrieval approach similar to operational SFMR (C-band frequencies respond to foam on ocean surface), but HIRAD adds wide swath instead of nadir trace
  - Minimum detectable wind speed ~35 kt (tropical storm force; ~ 15 m $s^{-1}$)
- **Future Goals:**
  - Upgrade to add wind direction
  - More robust 2nd-generation instrument(s)

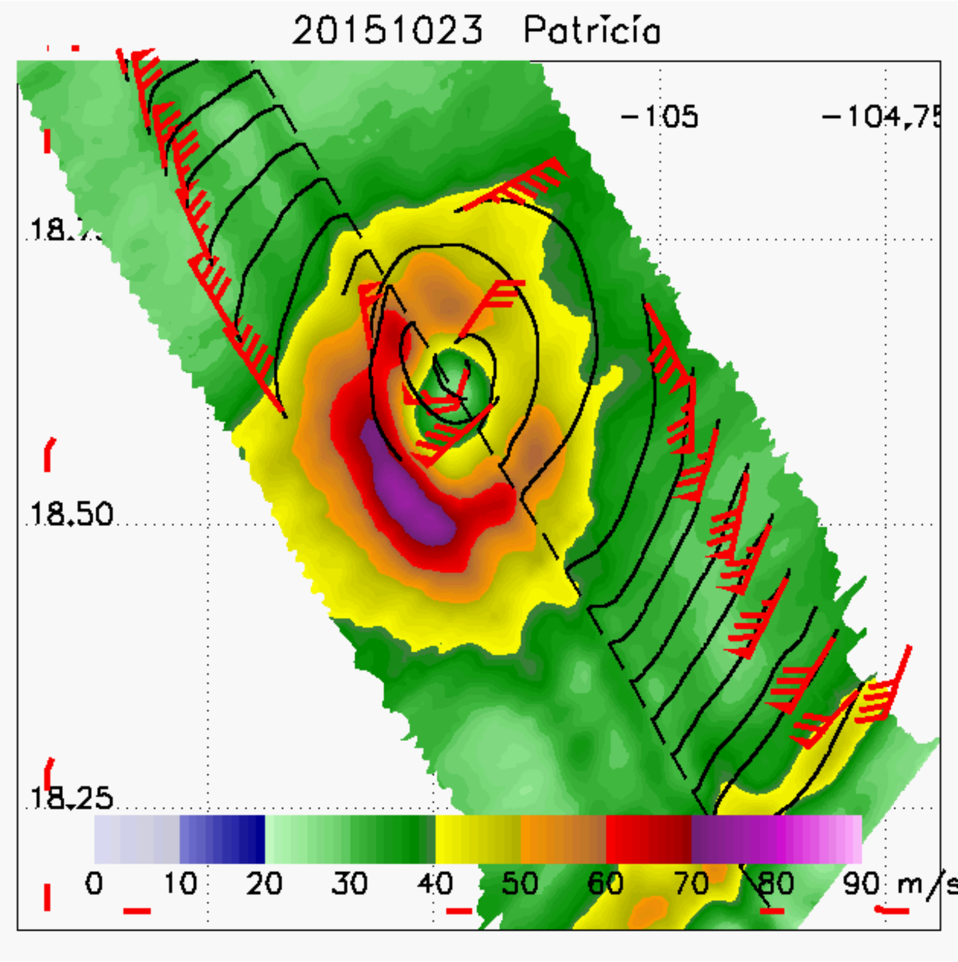



*Hurricane Patricia (2015) at Cat 5 intensity, with dropsonde wind barbs overlaid.*

*For a small storm like Patricia, one aircraft pass maps the entire eyewall.*

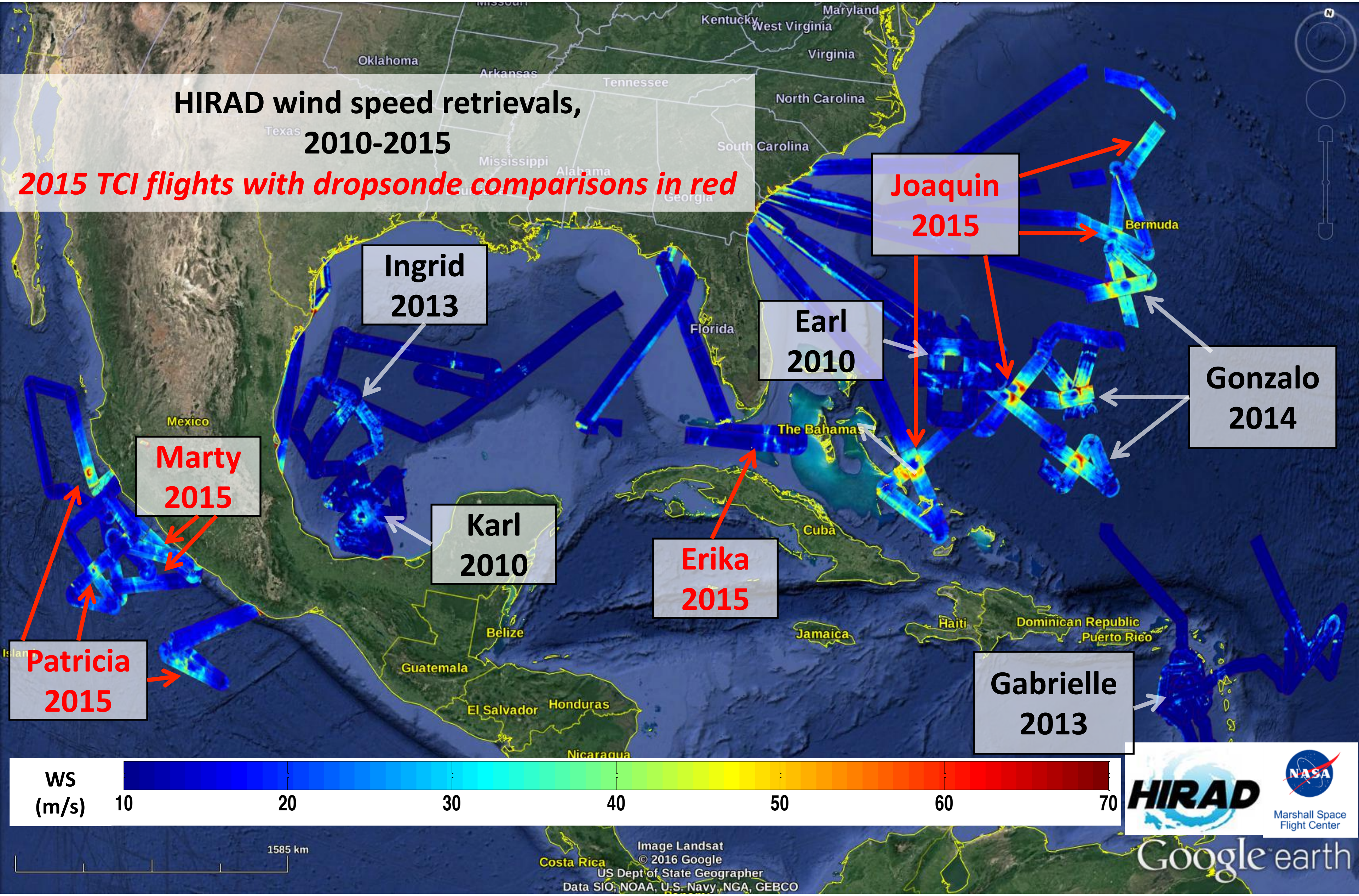
# Tropical Cyclone Intensity (TCI) Experiment

- **TCI**
  - Sponsored by Office of Naval Research
  - HIRAD and High Density Sounding System (HDSS) on NASA WB-57 in 2015
  - Hurricanes Joaquin, Patricia, Marty, and remnants of TS Erika
  - Aircraft based in Houston, but forward-deployed to Warner-Robins, GA for half the flights and Harlingen, TX for half the flights
  - Datasets available through NCAR EOL archive
- **This presentation:**
  - Quantitatively compare HIRAD retrievals to ~600 point estimates of surface wind speed, based on HDSS dropsondes
  - Dropsonde surface wind speed estimated from WL150 or MBL, following Uhlhorn et al. 2007 and Franklin et al. 2003




*Hurricane Patricia (2015) at Cat 5 intensity, with dropsonde wind barbs overlaid.*

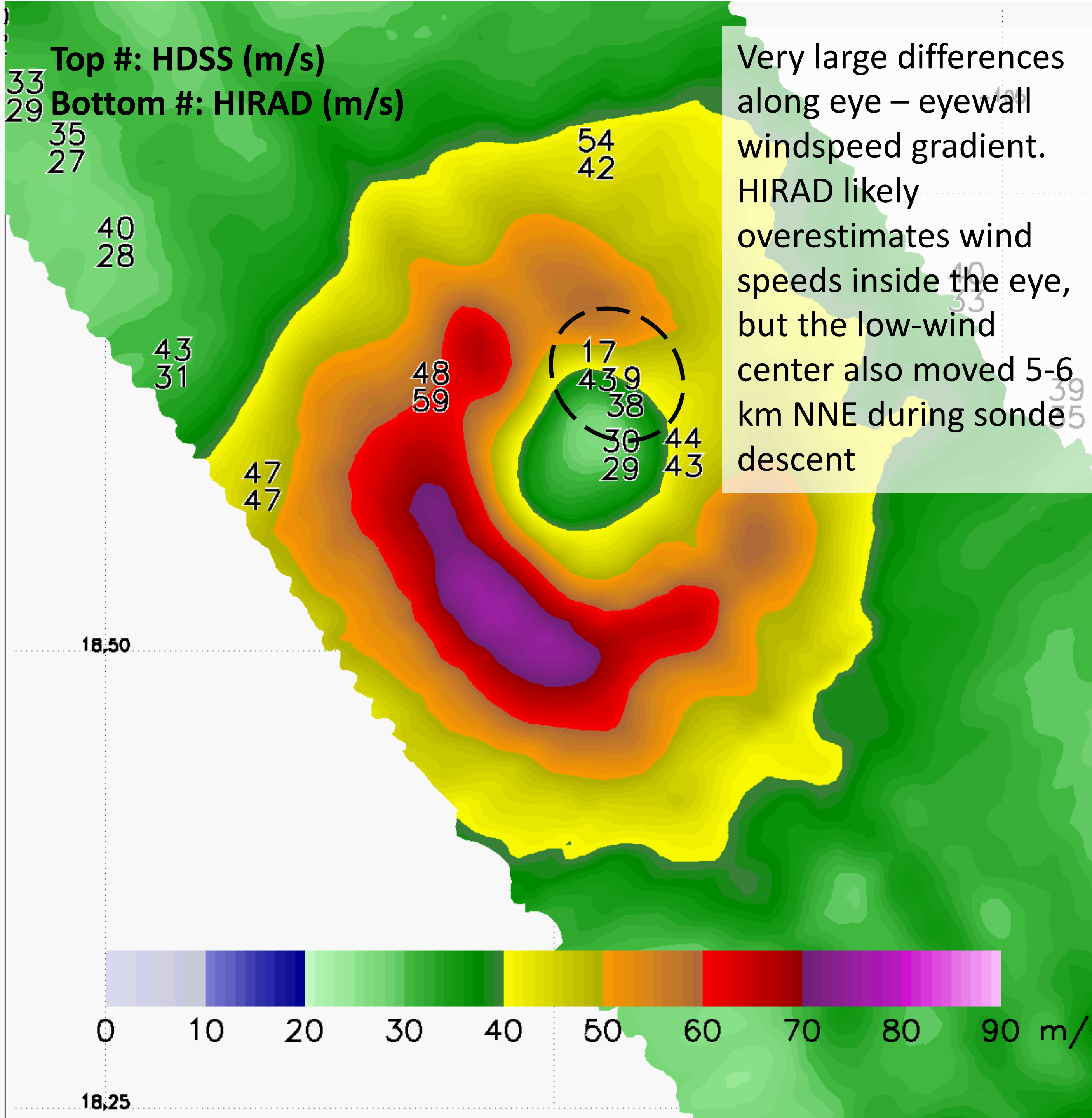
*For a small storm like Patricia, one aircraft pass maps the entire eyewall.*


HIRAD wind speed retrievals, 2010-2015
2015 TCI flights with dropsonde comparisons in red
Ingrid 2013
Karl 2010
Earl 2010
Joaquin 2015
Gonzalo 2014
Marty 2015
Patricia 2015
Erika 2015
Gabrielle 2013
WS (m/s)
10
20
30
40
50
60
70
Oklahoma
Arkansas
Tennessee
Kentucky
West Virginia
Maryland
Virginia
North Carolina
South Carolina
Georgia
Alabama
Mississippi
Texas
Florida
Bermuda
Mexico
The Bahamas
Cuba
Jamaica
Haiti
Dominican Republic
Puerto Rico
Belize
Guatemala
El Salvador
Honduras
Nicaragua
Costa Rica
1585 km
Image Landsat
© 2016 Google
US Dept of State Geographer
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
HIRAD
NASA
Marshall Space Flight Center
Google earth

Point-by-point comparisons of surface wind speed using 636 sondes.

Adjusted wind to surface using WL150 or MBL, following Uhlhorn et al. 2007 and Franklin et al. 2003

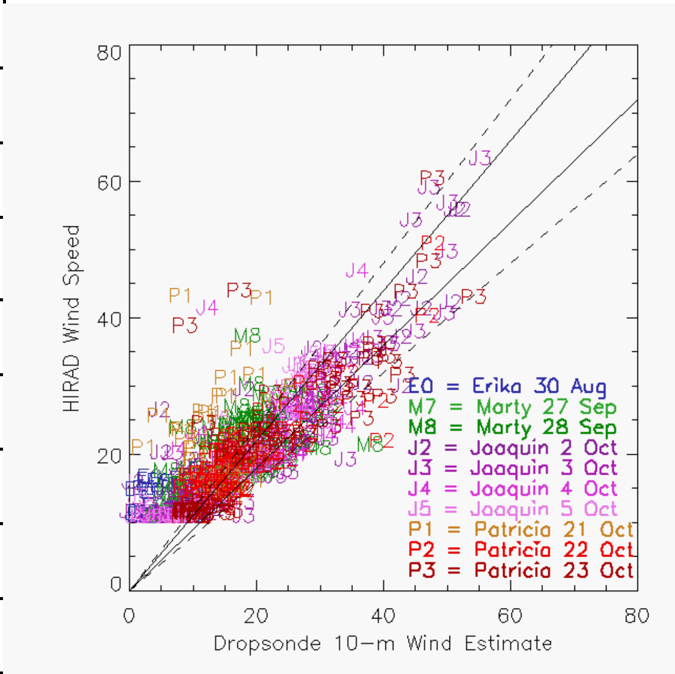
Did not account for storm moving a few km during 10-15 minute dropsonde descent




Very large differences along eye – eyewall windspeed gradient. HIRAD likely overestimates wind speeds inside the eye, but the low-wind center also moved 5-6 km NNE during sonde descent

# HIRAD – HDSS Differences by Flight

| HIRAD Wind Speed | Sample size | Bias (m $s^{-1}$) | | RMSD (m $s^{-1}$) | | MAD (m $s^{-1}$) | |
|---|---|---|---|---|---|---|---|
| Post-Erika 30 Aug | 46 | 5.7 | 47% | 6.7 | 54% | 5.7 | 47% |
| TS Marty 27 Sep | 50 | 2.0 | 13% | 4.4 | 28% | 3.8 | 24% |
| Hurricane Marty 28 Sep | 68 | 1.7 | 8% | 5.8 | 28% | 4.4 | 22% |
| Hurricane Joaquin 02 Oct | 73 | 1.6 | 12% | 5.7 | 30% | 4.2 | 23% |
| Hurricane Joaquin 03 Oct | 64 | -0.1 | 2% | 5.8 | 34% | 4.7 | 26% |
| Hurricane Joaquin 04 Oct | 73 | 0.0 | 2% | 5.8 | 29% | 4.0 | 21% |
| Hurricane Joaquin 05 Oct | 65 | 2.5 | 17% | 4.2 | 30% | 3.1 | 20% |
| TS Patricia 21 Oct | 57 | 5.5 | 21% | 9.4 | 36% | 6.5 | 28% |
| Hurricane Patricia 22 Oct | 71 | 0.0 | 0% | 4.4 | 23% | 3.4 | 18% |
| Hurricane Patricia 23 Oct | 69 | -0.4 | -3% | 6.7 | 23% | 4.1 | 17% |
| ***All*** | ***636*** | ***1.6*** | ***11%*** | ***6.0*** | ***31%*** | ***4.3*** | ***24%*** |
| *Excluding 30 Aug, 21 Oct* | *533* | *0.9* | *6%* | *5.4* | *28%* | *4.0* | *21%* |




Most flights had bias < 2 m $s^{-1}$

Erika and Patricia (21 Oct, during TS stage) had larger biases than the other flights

Also a few large outliers from eye-eyewall windspeed gradient in Patricia (23) and Joaquin (04)

# HIRAD – HDSS Differences by Wind Speed

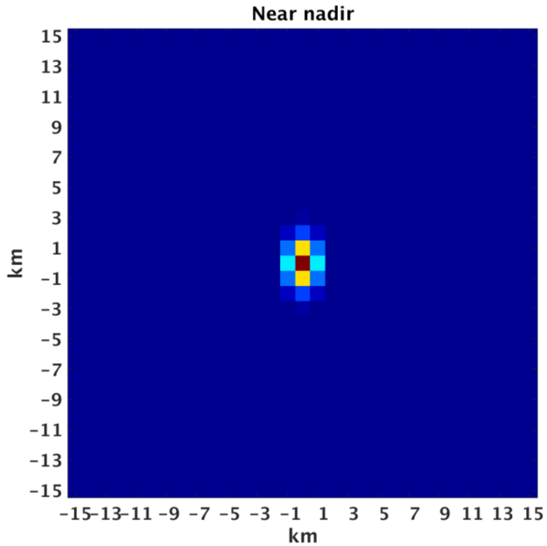
Using 636 sondes from 10 flights

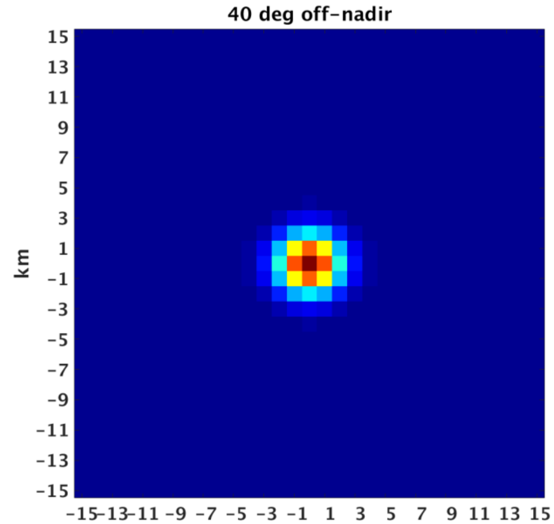
| HIRAD Wind Speed | Sample size | Bias (m $s^{-1}$) | | RMSD (m $s^{-1}$) | | MAD (m $s^{-1}$) | |
|---|---|---|---|---|---|---|---|
| < TS: < 17.5 m $s^{-1}$ | 304 | 2.2 | 18% | 4.5 | 36% | 3.5 | 27% |
| TS: 17.5 – 33.0 m $s^{-1}$ | 279 | 0.8 | 3% | 6.2 | 27% | 4.7 | 21% |
| Hurricane: > 33.0 m $s^{-1}$ | 53 | 3.2 | 7% | 10.7 | 26% | 7.2 | 18% |
| ***All*** | ***636*** | ***1.6*** | ***11%*** | ***6.0*** | ***31%*** | ***4.3*** | ***24%*** |

Omitting Erika, TS Patricia 21 Oct, and 3 dubious points from eye-eyewall gradient

| HIRAD Wind Speed | Sample size | Bias (m $s^{-1}$) | | RMSD (m $s^{-1}$) | | MAD (m $s^{-1}$) | |
|---|---|---|---|---|---|---|---|
| < TS: < 17.5 m $s^{-1}$ | 235 | 1.7 | 14% | 4.1 | 33% | 3.2 | 25% |
| TS: 17.5 – 33.0 m $s^{-1}$ | 248 | -0.1 | -1% | 5.6 | 25% | 4.3 | 19% |
| Hurricane: > 33.0 m $s^{-1}$ | 47 | 0.3 | 0% | 6.3 | 16% | 4.8 | 12% |

# Effects of footprint size

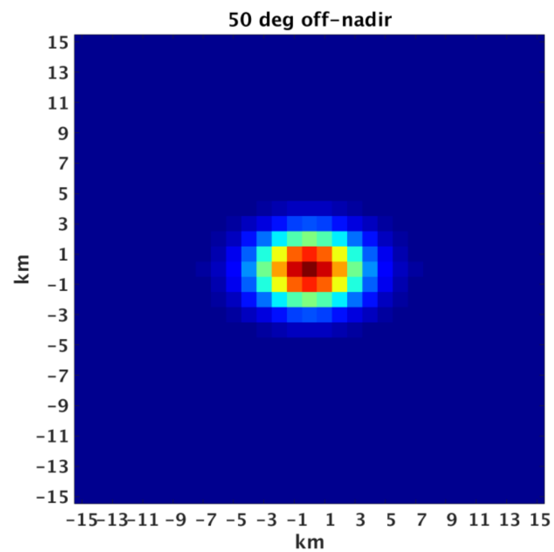


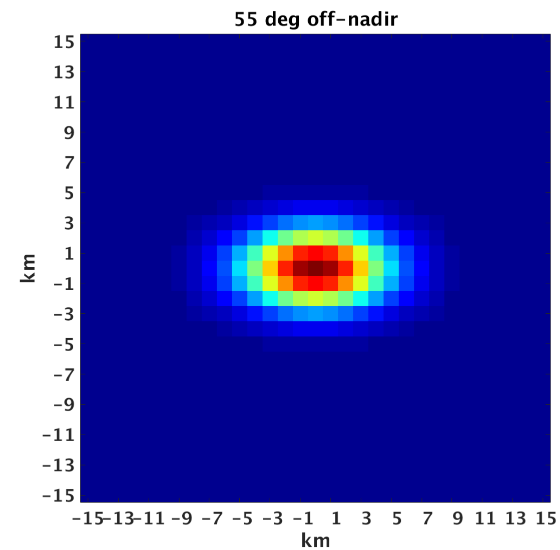




**Antenna Pattern Smoothing Weights**

The shape changes from an along track oriented ellipse ( ~ near nadir) to a circle ( ~ 40 deg) and then back to an ellipse whose semi-major axis oriented along the xtrack direction.

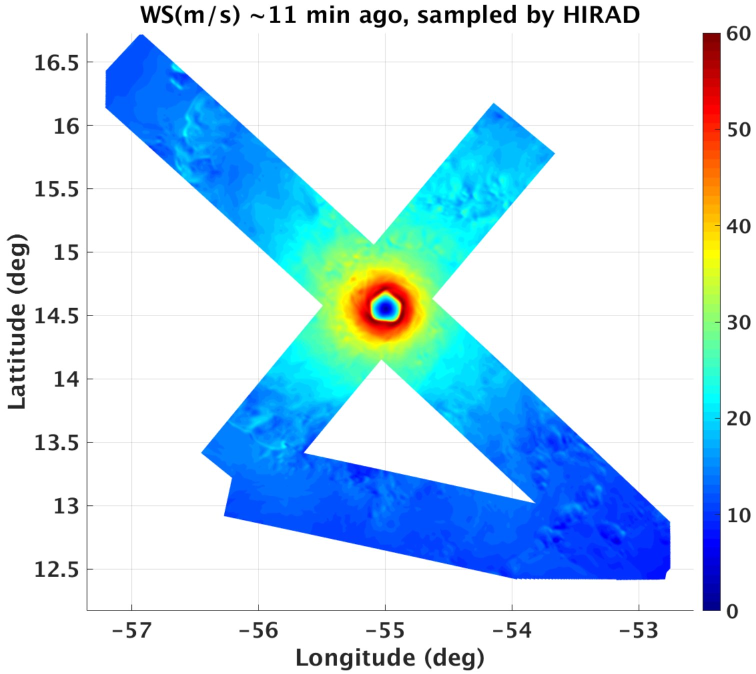
Near circular footprint (40 deg off-nadir)



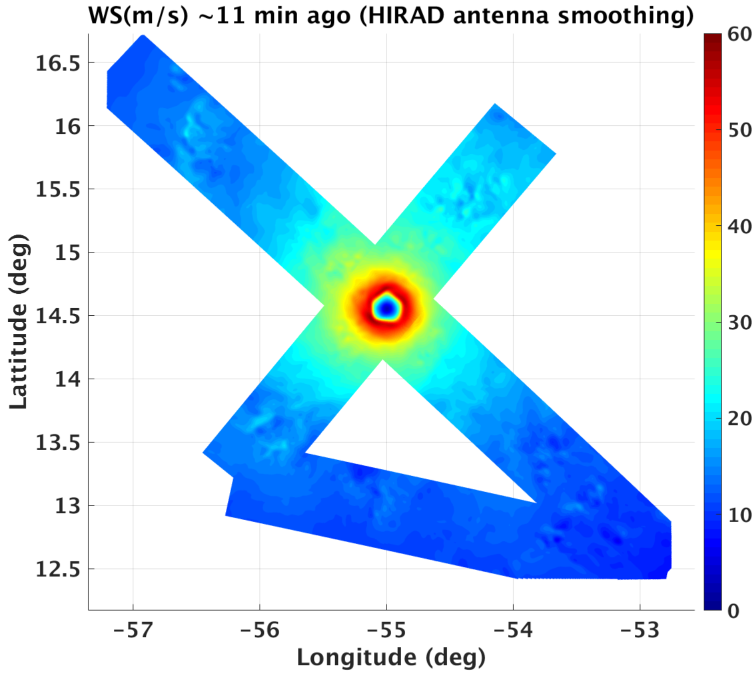



# Effects of footprint size

Take a 1-km idealized simulation from Nolan, and subset a +/-60° HIRAD swath:

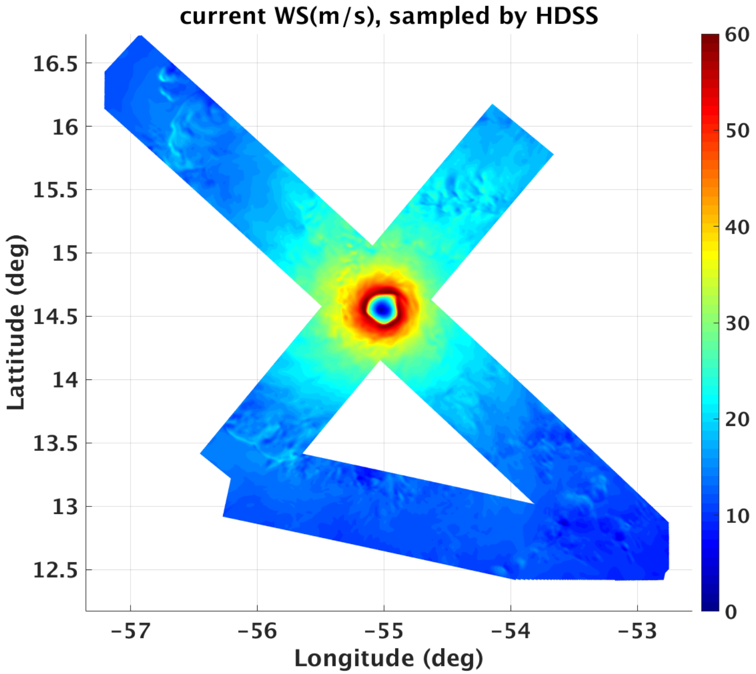



Apply smoothing to match HIRAD's footprint sizes at different incidence angles across a swath:



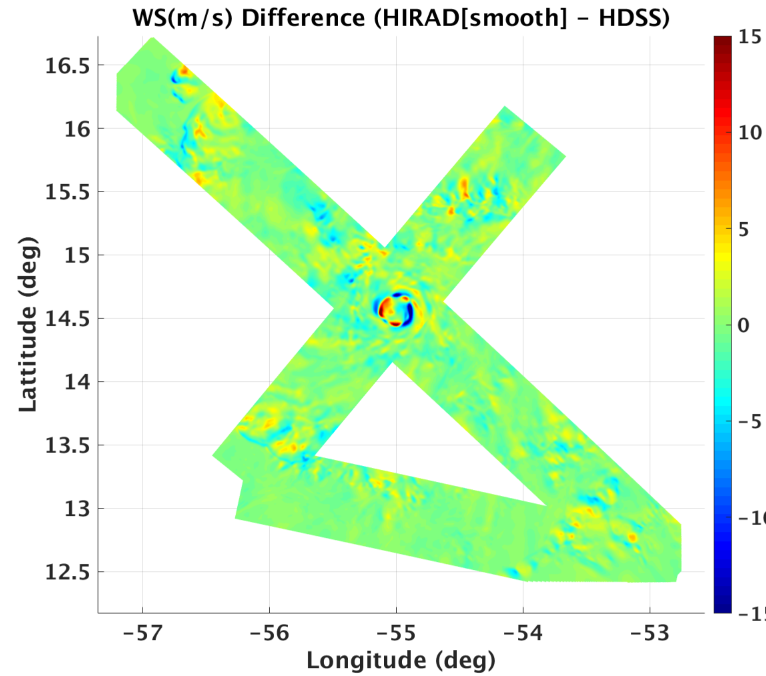
# Effects of footprint size & temporal mismatch

Take idealized surface wind field 10 minutes later, simulating the conditions a dropsonde would fall into:




*Dropsondes typically took 10-15 minutes to descend from WB57 flying near 60,000 ft*

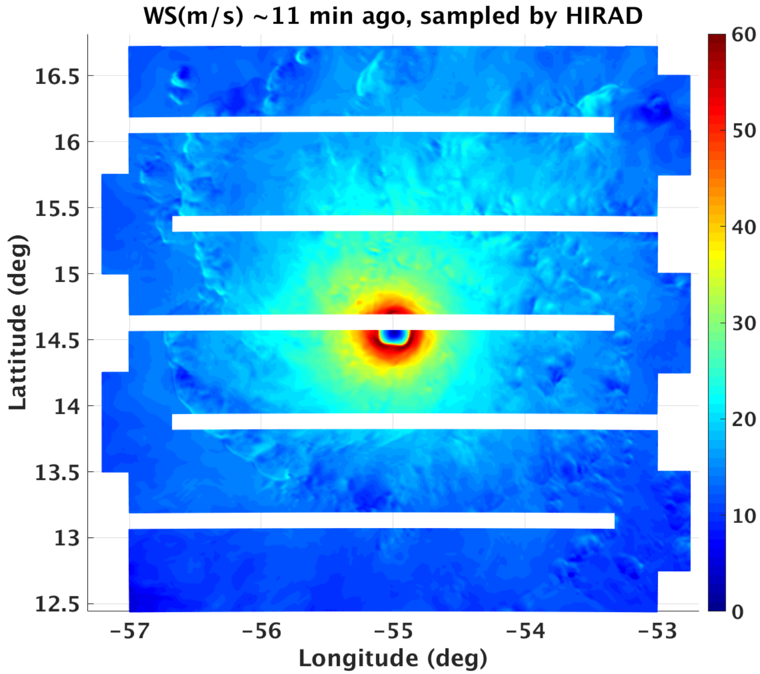
Compute difference, accounting for HIRAD beam smoothing and temporal evolution during dropsonde descent:




***Differences range from -22 to + 19 m $s^{-1}$***

# Same thing applied to a lawnmower pattern (~4 – 4.5 hr duration for ~400 kt aircraft at FL600)

Take a 1-km idealized simulation from Nolan , and subset a +/-60° HIRAD swath :

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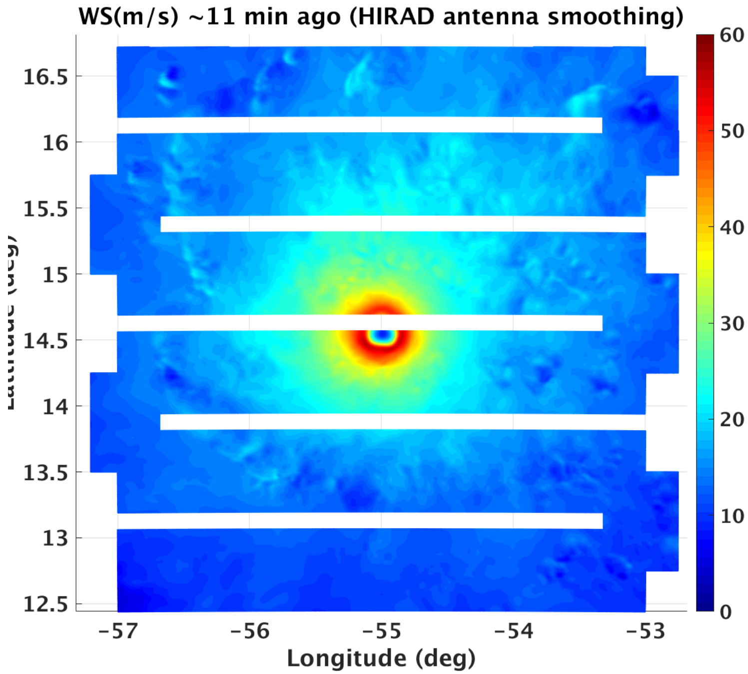

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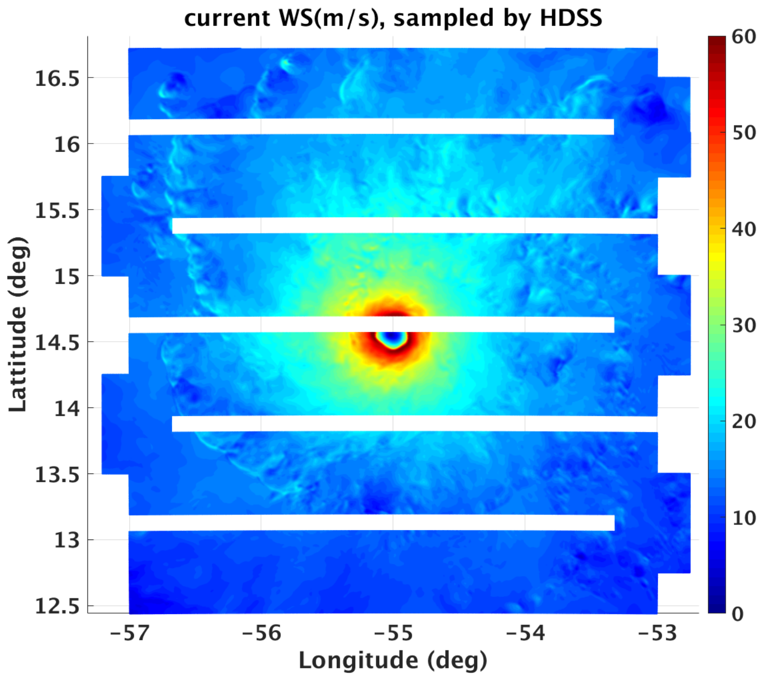
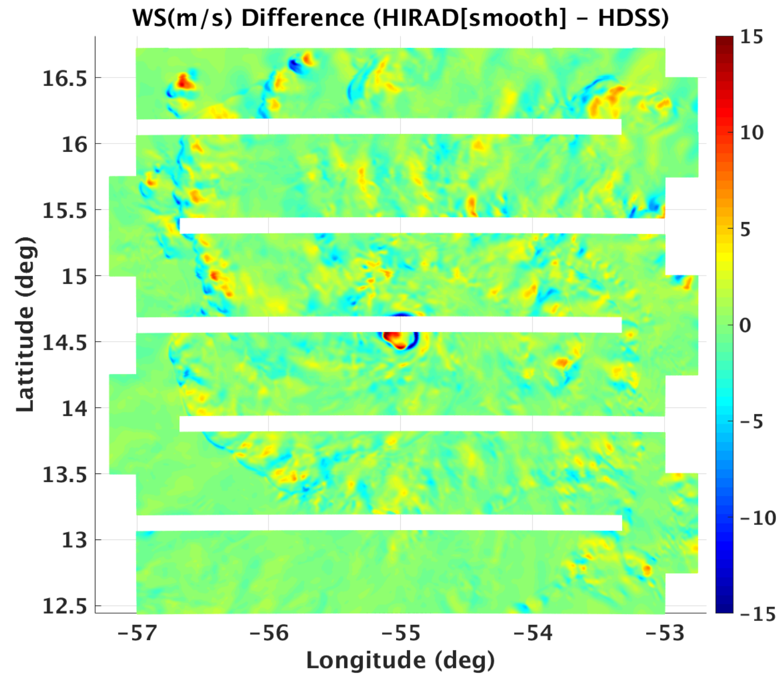



Compute difference, accounting for HIRAD beam smoothing and temporal evolution during dropsonde descent:




*Dropsondes typically took 10-15 minutes to descend from WB57 flying near 60,000 ft*

***Differences range from -23 to + 22 m s$^{-1}$***

# HIRAD – HDSS Differences by Wind Speed

- Even perfect measurements & perfect retrievals would have some differences exceeding 20 m $s^{-1}$, when compared against dropsondes
- The idealized model output suggests ~ 2-3 m $s^{-1}$ RMS Difference would be expected even with perfect measurements from both HIRAD and dropsondes
- Estimating HIRAD error requires accounting for that, and accounting for uncertainty in dropsonde-based estimate of surface wind

$$RMSE_{HIRAD} \sim ( RMSD_{(HIRAD\text{-}SONDE)}{}^2 - RMSD_{SONDE}{}^2 - RMSD_{(spatio\text{-}temporal\ mismatch)}{}^2 )^{0.5}$$

$$RMSE_{HIRAD} \sim \ sqrt( (6.0\ m\ s^{-1})^2 - (3.1\ m\ s^{-1})^2 - (2.0\ m\ s^{-1})^2 )^{0.5}$$

$$RMSE_{HIRAD} \sim \ 4.7\ m\ s^{-1}$$

*From Uhlhorn et al. 2007 evaluation of using WL150 to get surface wind speed*

# Summary

- HIRAD surface wind speed retrievals evaluated using HDSS dropsonde intercomparison for 636 sondes, 10 flights during 2015 TCI project
- Performance looks good across all incidence angles
- Bias < 2 m $s^{-1}$; near zero for most flights
- RMS Difference about 6 m $s^{-1}$
- Largest differences likely associated with motion of the eyewall during the dropsonde's 10-15 minute descent (*the wind scene is imaged by HIRAD before the dropsonde reaches the surface*)

# Summary

- RMSE Error estimated to be ~4-5 m $s^{-1}$, accounting for uncertainties in dropsonde surface wind speed estimates *and* spatio-temporal mismatches in the comparisons
- Simply eliminating the most dubious HIRAD-dropsonde matchups reduces the RMSD to ~5 m $s^{-1}$, computed across all intensities

*Omitting Erika, TS Patricia 21 Oct, and 3 dubious points from eye-eyewall gradient:*

| HIRAD Wind Speed | Sample | Bias (m $s^{-1}$) | | RMSD (m $s^{-1}$) | | MAD (m $s^{-1}$) | |
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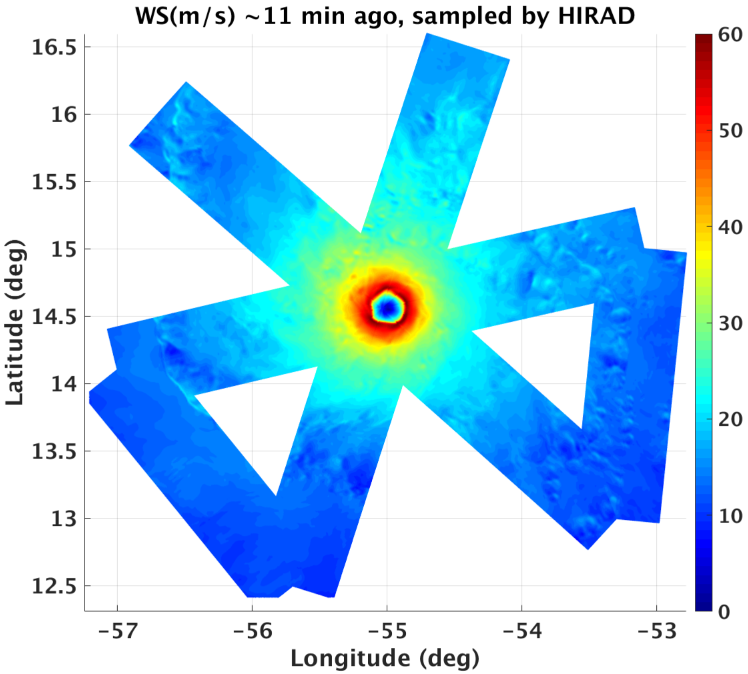
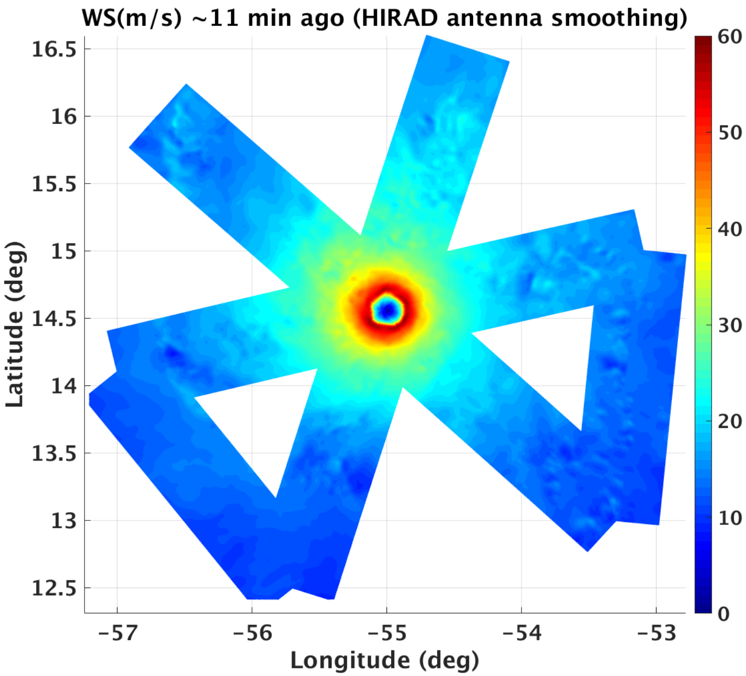
| Hurricane: > 33.0 m $s^{-1}$ | 47 | 0.3 | 0% | 6.3 | 16% | 4.8 | 12% |

# Backup – Butterfly Pattern

Take a 1-km idealized simulation from Nolan, and subset a +/-60° HIRAD swath:

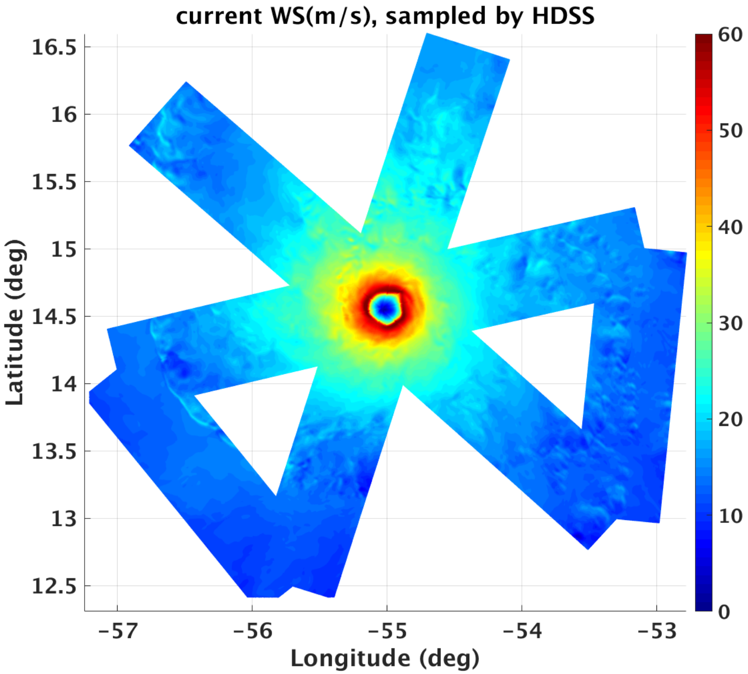



Apply smoothing to match HIRAD's footprint sizes at different incidence angles across a swath:

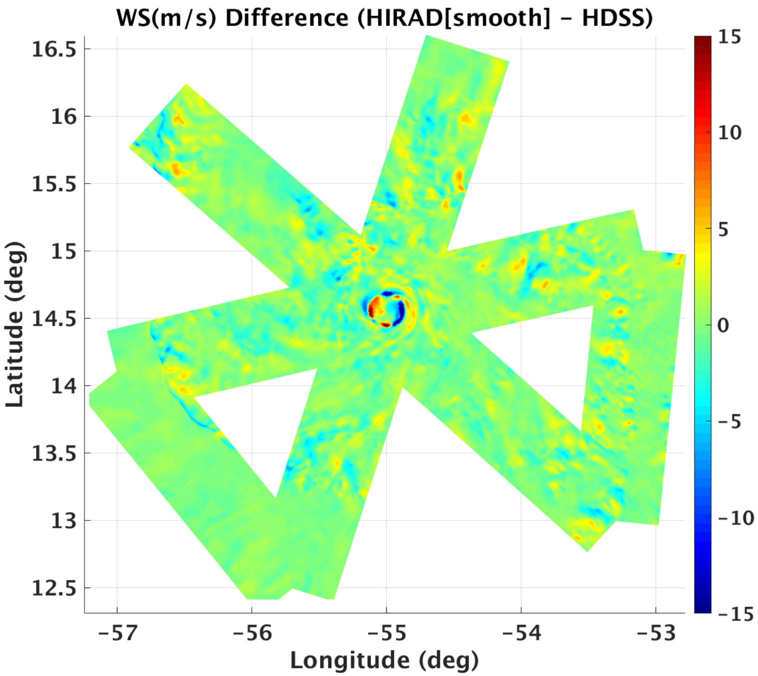


# Effects of footprint size & temporal mismatch

Take idealized surface wind field 10 minutes later, simulating the conditions a dropsonde would fall into:




Compute difference, accounting for HIRAD beam smoothing and temporal evolution during dropsonde descent:




*Dropsondes typically took 10-15 minutes to descend from WB57 flying near 60,000 ft*